The Value of Range: The Market Penetration of Alternative-Fuel Vehicles

David A. Poyer and Dan Santini

presented at the

Transportation Research Board
Washington, D.C.
January 11, 1999

This research was sponsored by DOE's Office of Transportation Technology (OTT) Dr. Phil Patterson, Program Manager

- OTT's primary goal is to reduce the annual increase in the use of petroleum fuels by highway transportation vehicles to zero or less.

Objective

- To assess the incremental impact of changes in vehicle range on consumer choice.

OTT funded data collection for the "National Survey."

- A stated-preference survey of the contiguous United States excluding California

- Modeled after California survey conducted by the University of California's Institute for Transportation Studies

A revised model was developed in 1998 whose coefficients are used by EIA and OTT.

- Purchase price
- Fuel cost (for both gasoline and alternative fuel)
- Maintenance cost (battery cost folded in for EVs & HEVs)
- Availability of alternative fuel (% of gasoline)
- Home refueling (yes/no)
- Range (on alternative fuel and on gasoline, as applicable)
- Acceleration (0-30 mph)
- Number of alternative-fuel vehicles on the road "in region"
- Luggage space (either 100% or 67% of gasoline vehicle)
- Top speed

Note: Results for and effects of underlined variables are presented here.

Numerous discrete choice models were estimated, evaluated, and refined.

- Stated-preference data were used.
- Multinomial and conditional logit models were estimated.
- Periodic verification of results were conducted.

There were a number (actually a whole lot) of database management preliminaries.

- Full database contains 33,677 records
- Total of 17 choices in 2 sets of respondent selection cards — used & new vehicles: ‘98 & ‘01
- Estimated data set constrained to households selecting new vehicles
- Condensed data set contains 17,489 records
- Represents 1,440 households
- Choices ranged from 4 to 17 new vehicles

Descriptive Statistics on Range by Detailed Vehicle and Fuel Type

Types in Estimate	Types in Data Base	Average	Standard Deviation	Minimum	Maximum
Gasoline	Gasoline	324	51	250	400
Alternative Fuel (Dedicated)	Dedicated	215	36	175	300
	Gaseous+ Dedicated Electric*	103	44	40	200
Multi-Fuel (Alternative Fuel and Gasoline)	Flex-Fuel Alcohol	312	47	250	400
	Dual Fuel	398	63	280	525
	Gaseous+ Hybrid Electric*	299	64	210	470

* means that all vehicles had home refueling; + means that some sample vehicles had home refueling; no home refueling otherwise

In the model estimated, vehicle range was grouped into three categories.

Fuel Type	Average	Standard Deviation	Minimum	Maximum
Gasoline (Dedicated)	324	51	250	400
Alternative Fuel (Dedicated)	149	69	40	300
Multi-Fuel	335	68	210	525

A series of MNL models were specified and estimated.

$$\Pr ob[y_t = j] = \exp(\beta' x_{jt}) / \sum_{i}^{n} \exp(\beta' x_{it})$$

We start with an examination of range alone.

- As expected, vehicle range and market share are positively related. Market share of conventional gasoline-fueled vehicles is most sensitive.

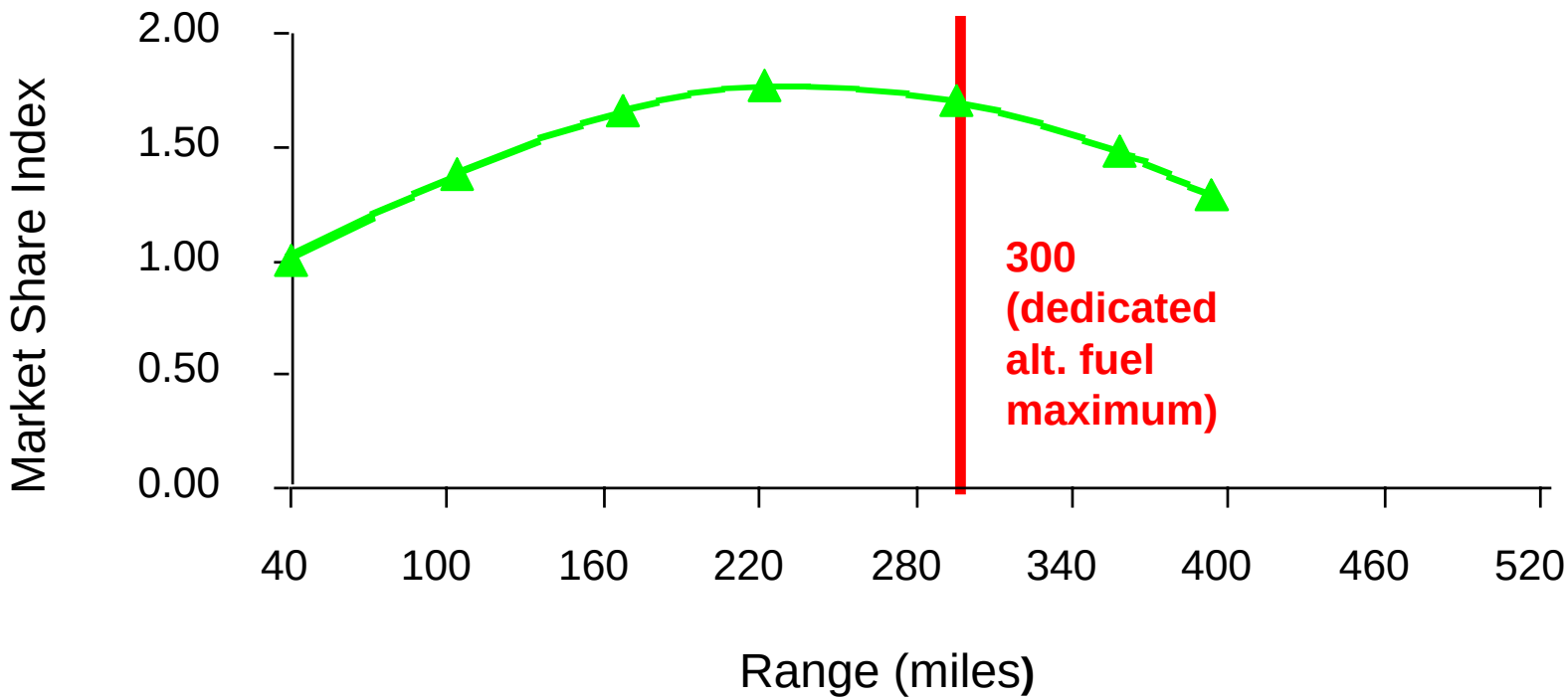
Parameter Estimates for Range-Related Variables

Coefficient	Estimate	Standard Error	Z-Value
Gasoline Linear	8.03E-03	1.99E-03	4.041
Gasoline Quadratic	-1.66E-05	4.21E-06	-3.951
Dedicated AFV	2.01E-03	1.43E-03	1.405
Multi-Fueled Linear	2.44E-03	1.61E-03	1.522
Multi-Fueled Quadratic	-3.39E-06	2.86E-06	-1.187

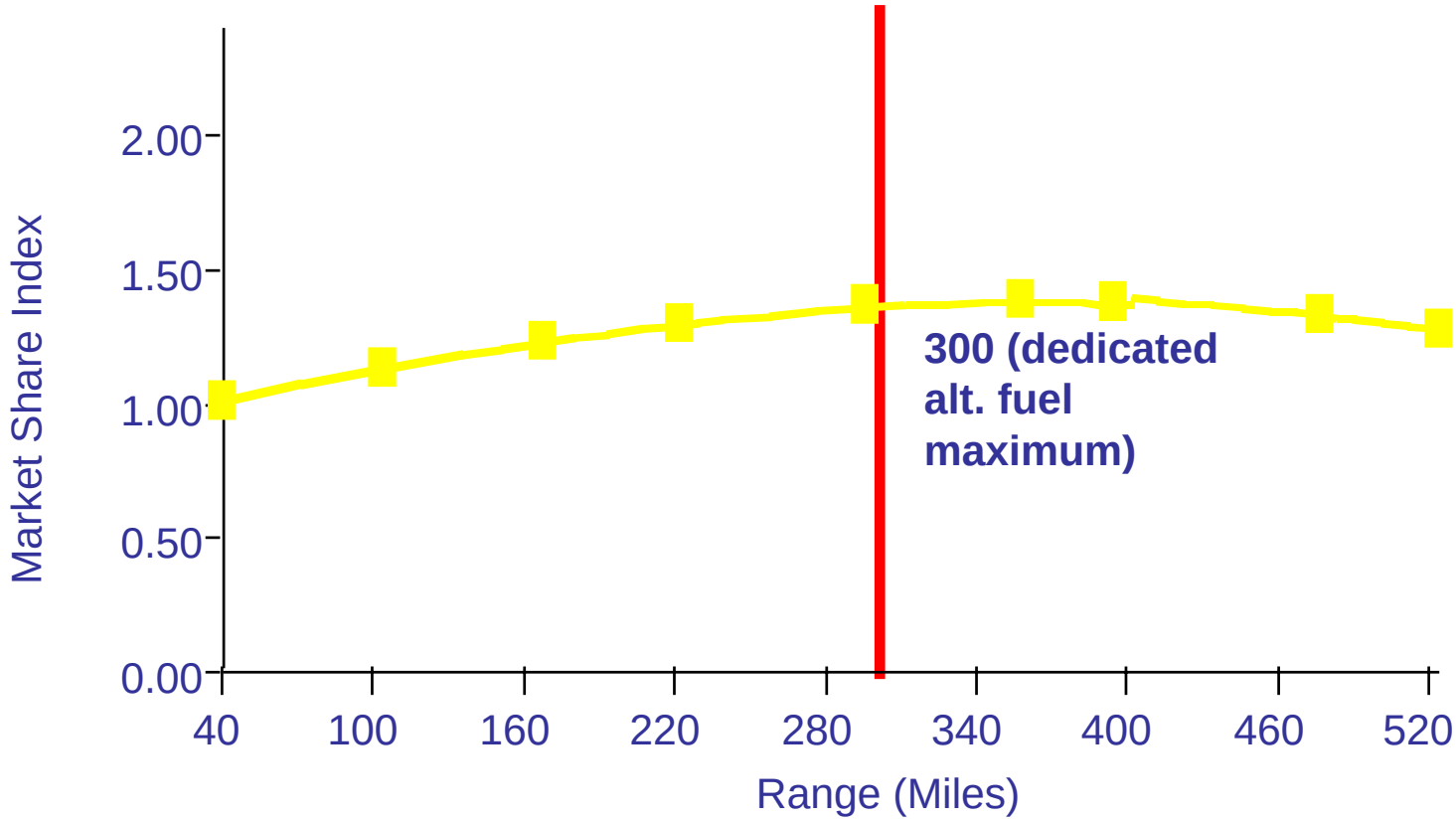
The addition of quadratic range terms significantly improves the model fit.

Model	Log-Likelihood Value	Chi-Square	Level of Significance
No Range Variables	-3326.709	NA	NA
Range Linear	-3323.217	6.98	0.10
Range Quadratic	-3315.220	22.98	0.005

Change in Gasoline Market Share in Response to Changes in Range.

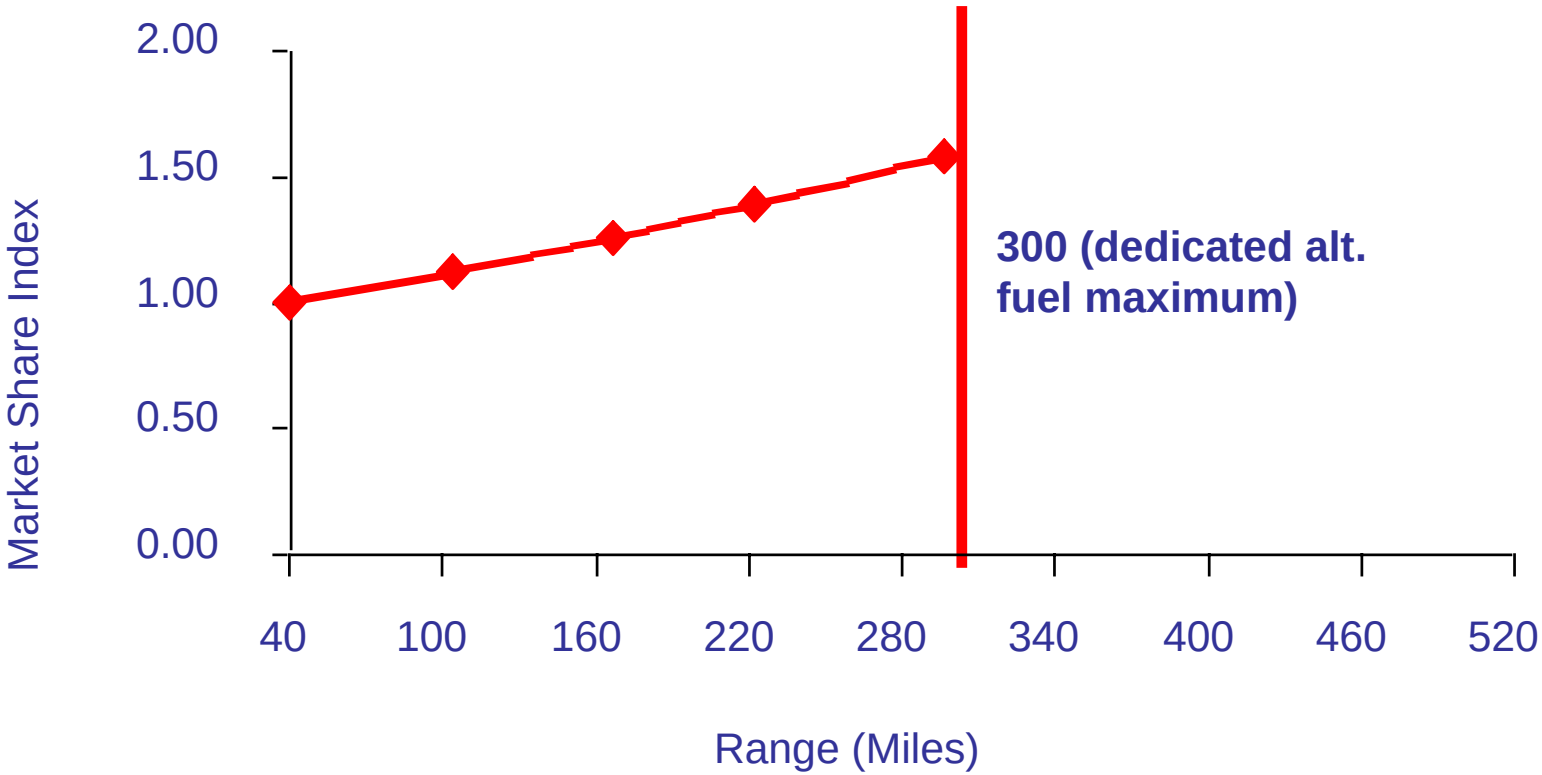


Change in Multi-fuel Vehicle Market Shares in Response to Changes in Range



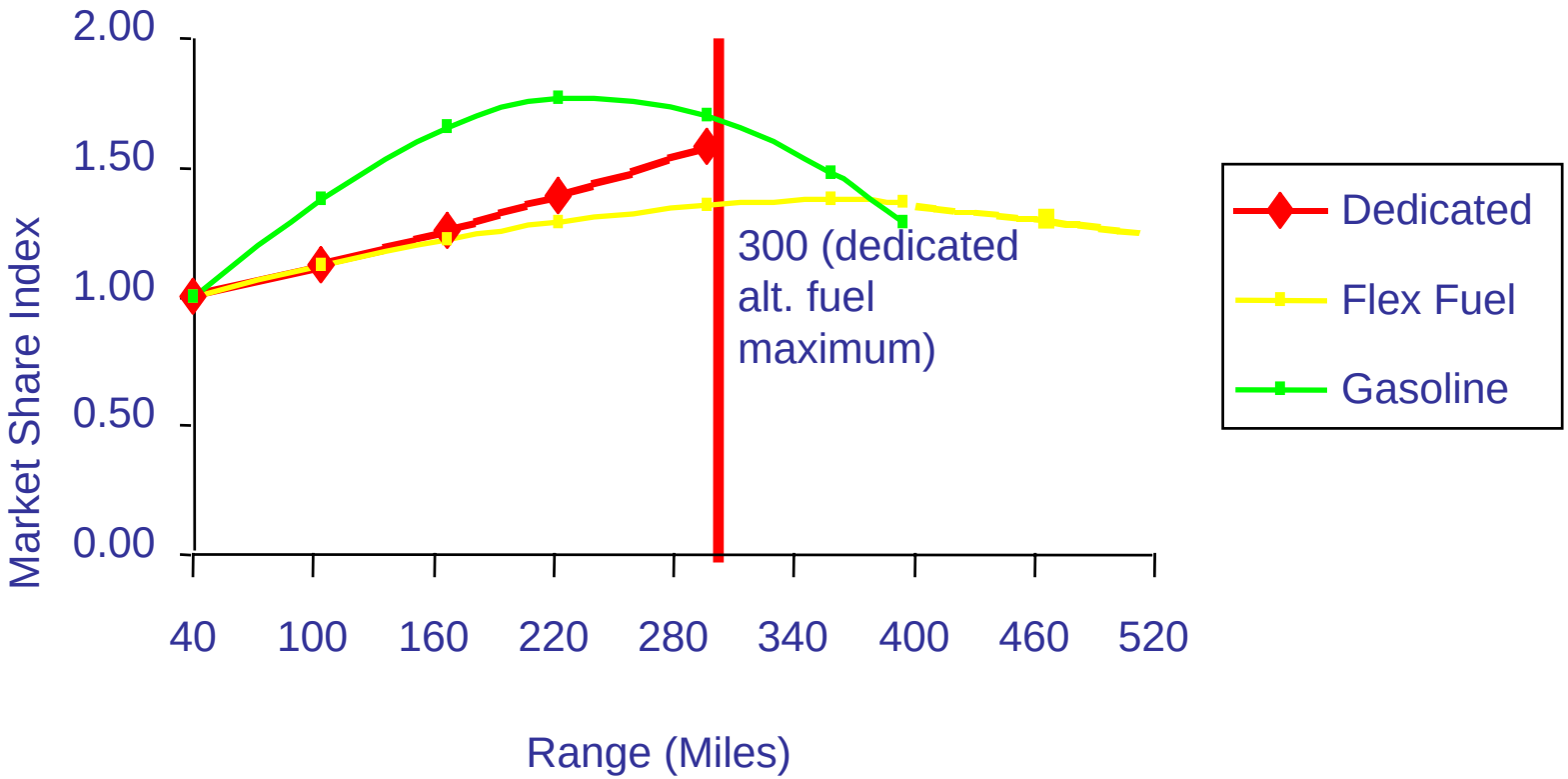
Note: Gasoline plus alternative fuel. Minimum alternative fuel availability is 5% of the gasoline total, and many of the vehicles in this set have home refueling

Change in Dedicated AFV Market Share in Response to Changes in Range: Dedicated AFV



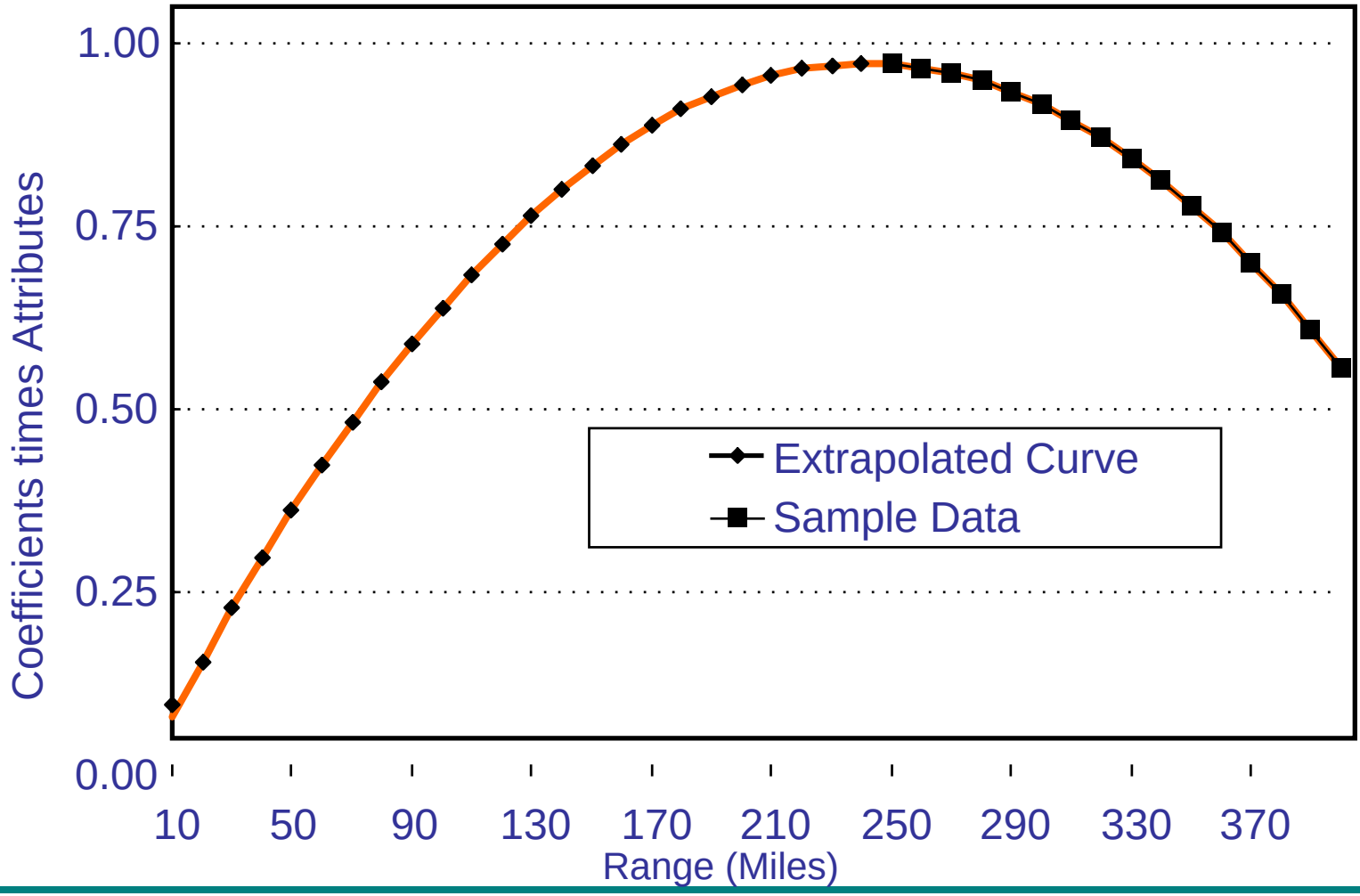
Note: Either electric or natural gas. Minimum alternative fuel availability is 5% of the gasoline total. All electrics have home refueling, many gas vehicles do also.

Change in Market Share in Response to Changes in Range: Gasoline vs Alternative-Fuel Types

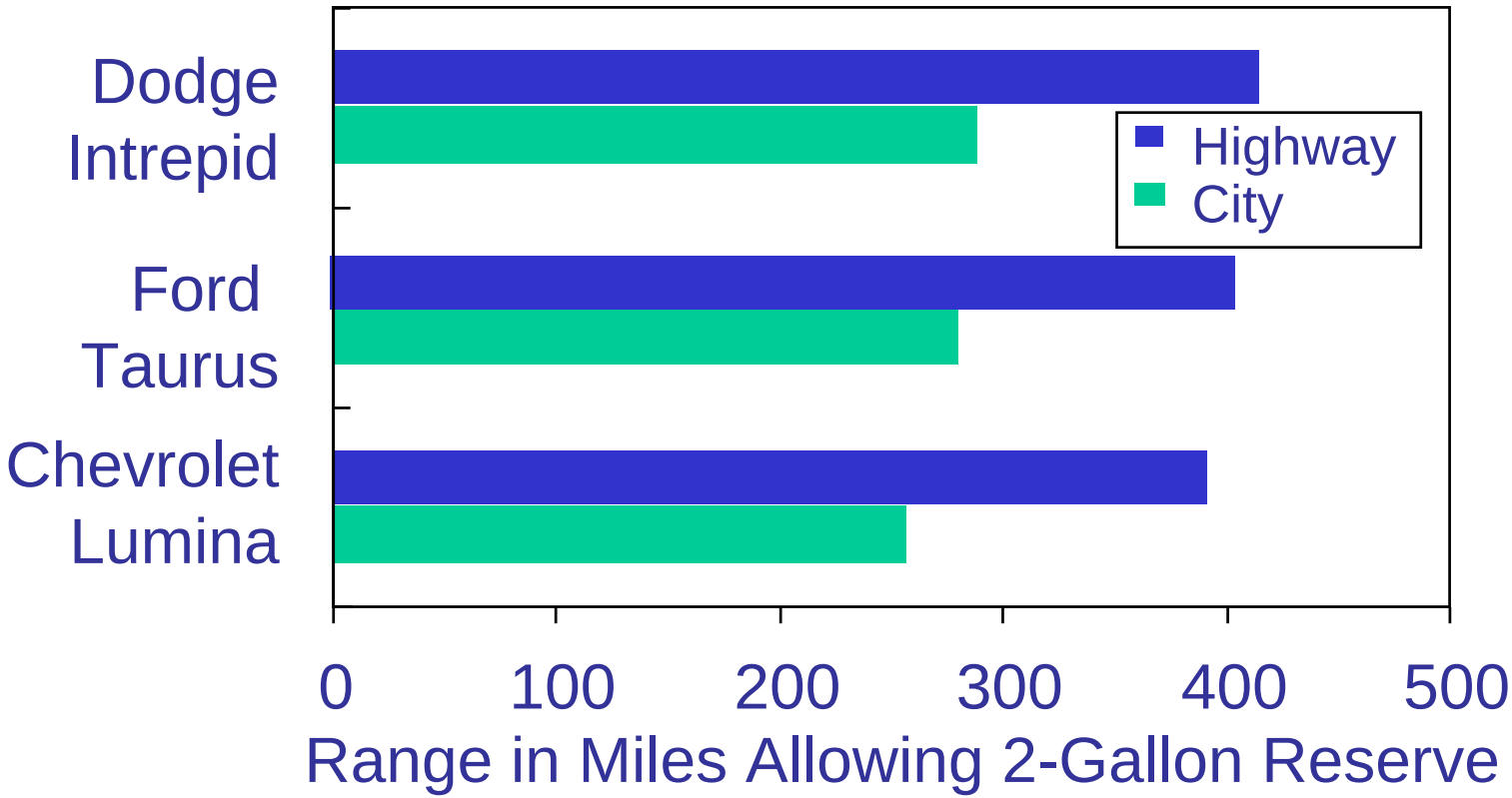


Note: The vast majority of the dedicated fuel vehicles seen by respondents have home refueling, but none have more than 25% station fuel availability of gasoline

Repeated tests confirmed that respondents thought a gasoline LDV could have too much range.



Practical city driving range is near the estimated optimum for gasoline vehicles.



The vehicle descriptors did not specify "city" or "highway" range. If respondents judged acceptable range by normal experience -- until the fuel light comes on in everyday driving -- the response on desired gasoline range is then logical.

The context of the typical respondent's evaluation of the value of range for AFVs is important.

- Most AFVs included home refueling.
- All AFVs had information that the alternative fuel was available at a minimum of 5% of gasoline stations and a maximum of 25%.
- Also, the only other variable unique to AFVs was the "number of AFVs on the road in your region" variable.

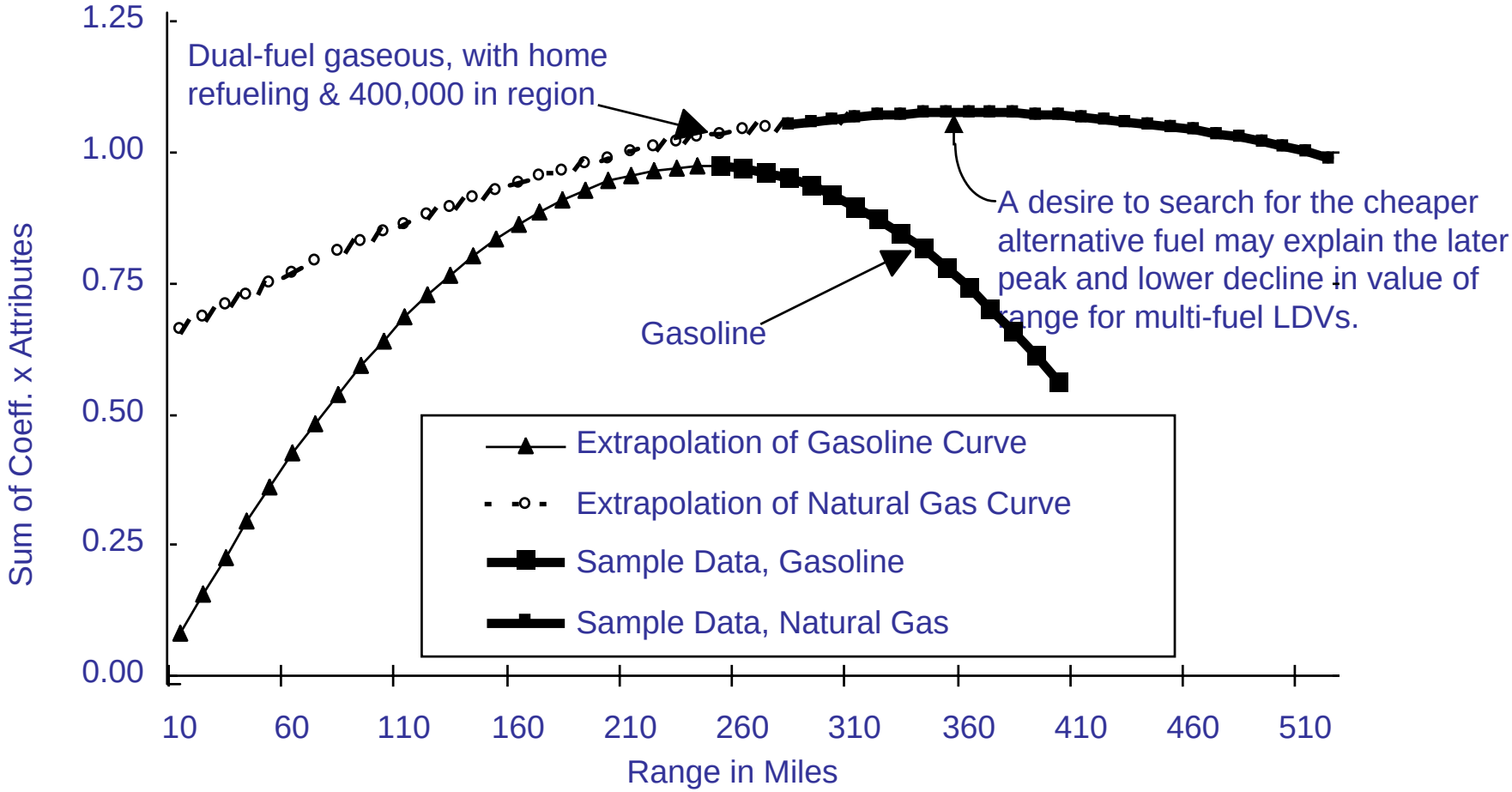
The importance of range interacted with the availability of fuel and home refueling.

The desirability of AFVs was only weakly related to AFVs on the road.
If others owned cleaner vehicles, the respondent didn't have to.

Variable	Coefficient	Estimate	Standard Error	Z-Value
Alternative fuel availability (% of gas stations with alt fuel [5-10+%])	Only for dedicated gaseous-fuel vehicles without home refueling+	4.58E-02	2.05E-02	2.23
Home refueling dummy (1 with, 0 without)	Home refueling*	1.32E-01	1.30E-01	1.02
Number of vehicles on the road "in your region"#	EVs, HEVs, and dedicated gaseous	-7.28E-04	6.74E-04	-1.08
	Flex-fuel and dual-fuel gaseous	1.03E-03	1.28E-03	0.81
	Flex-fuel and dual-fuel gaseous (squared)	5.67E-07	3.42E-06	0.17

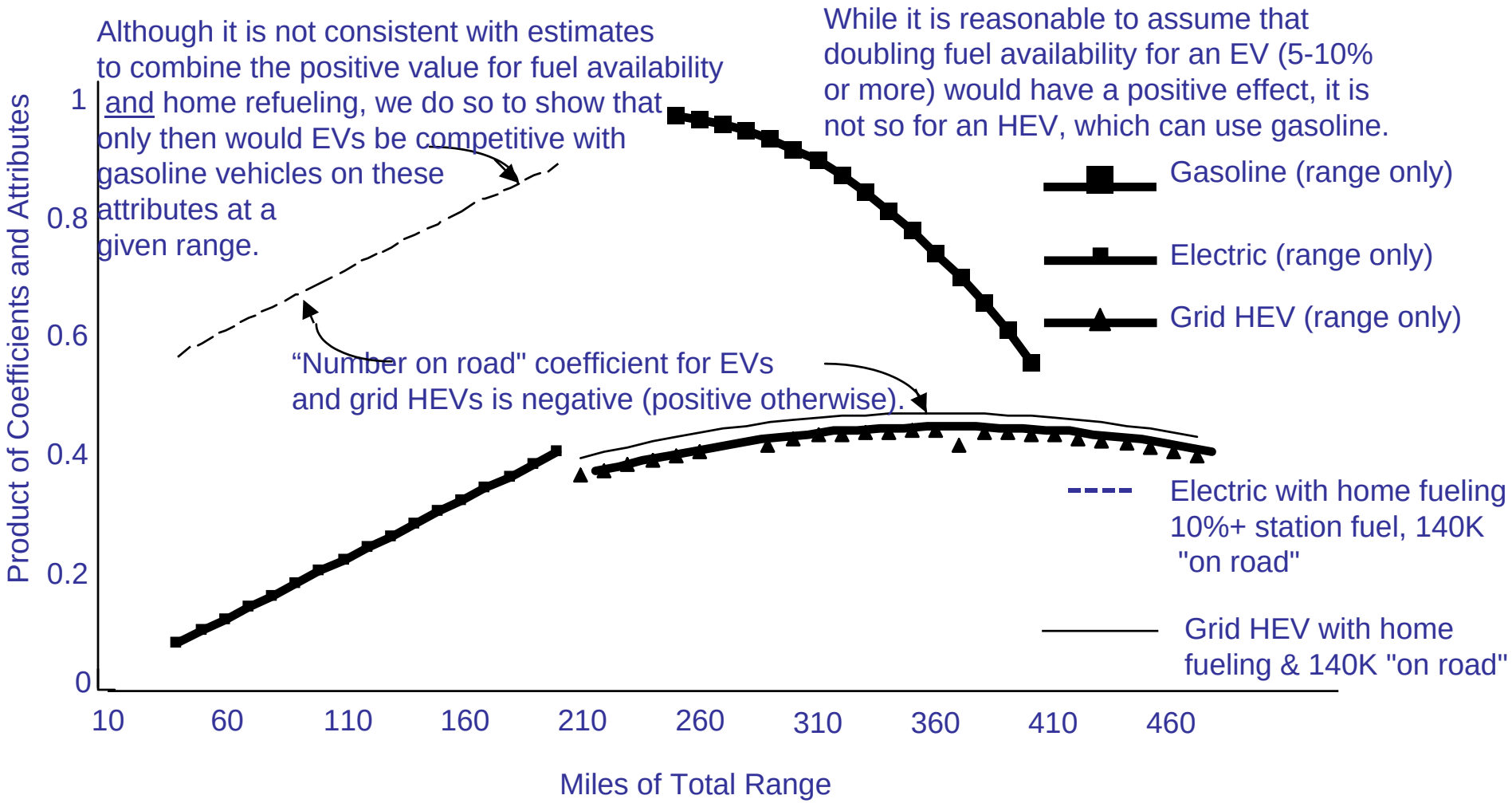
+ When home-refueled vehicles were tested or included, there was no significant desire for greater than 5% fuel availability.
*As absence of home refueling is not an important determinant of the fuel availability coefficient, home refueling value is also estimated.
#Although these coefficients are not significantly different from zero, earlier tests indicated that the group results are significantly different from one another, and the interpretations of the differences may be of interest. The vehicles with negative coefficient were those portrayed as cleanest among the AFVs.

If dual-fuel CNG LDVs had home refueling and 400,000 were "in the region," they could compete with gasoline LDVs on this set of attributes.

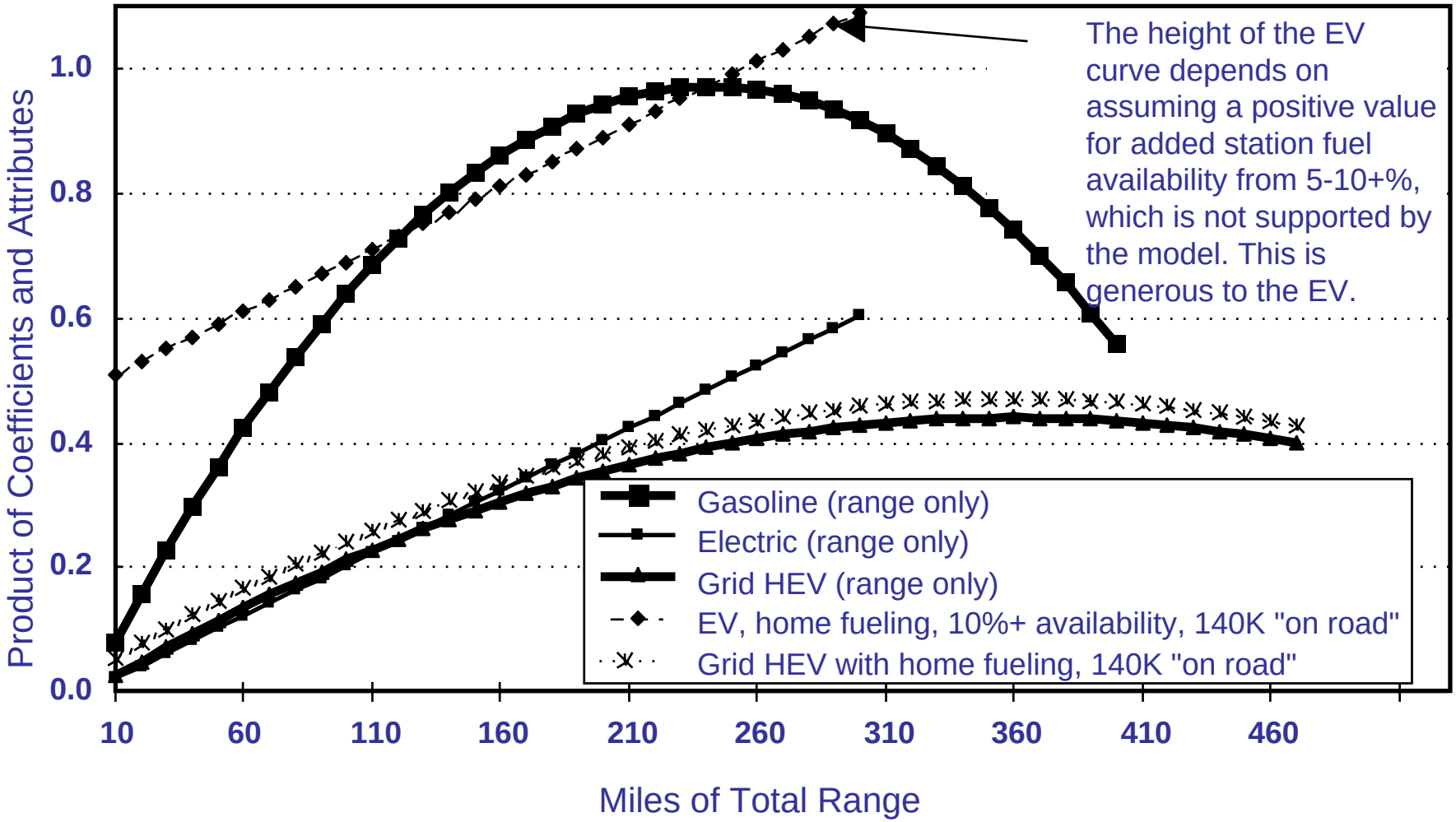


Note: All survey respondents saw alternative fuel available at a minimum of 5% and maximum of 25% of gasoline stations, so all assumed that the fuel could be purchased, albeit with some searching. The fuel availability coefficient in this case is "0," but it means that there is no additional value to fuel availability above 5%

Selected values for gasoline, EV, and grid HEV LDVs, for sample range, show gasoline is preferred, considering range only, without home refueling.



For the four variables, EVs can be as attractive as gasoline vehicles if they can go 100-250 miles, but grid HEVs cannot.



When evaluating the four variables, EVs seem to have a better rating than HEVs.

- But...We have not yet considered price and fuel cost, nor have we examined the two major HEV types.
- The survey assumed that a grid-independent (PNGV-type) HEV would use gasoline and be seen by the consumer as a gasoline vehicle. Very low fuel costs were provided to test for response to big increases in fuel efficiency of gasoline vehicles.
- All “HEVs” seen by respondents were “grid connectable” with home refueling. Electricity was available at 5-25% of stations.
- All EVs had home refueling. Electricity was available at 5-25% of stations

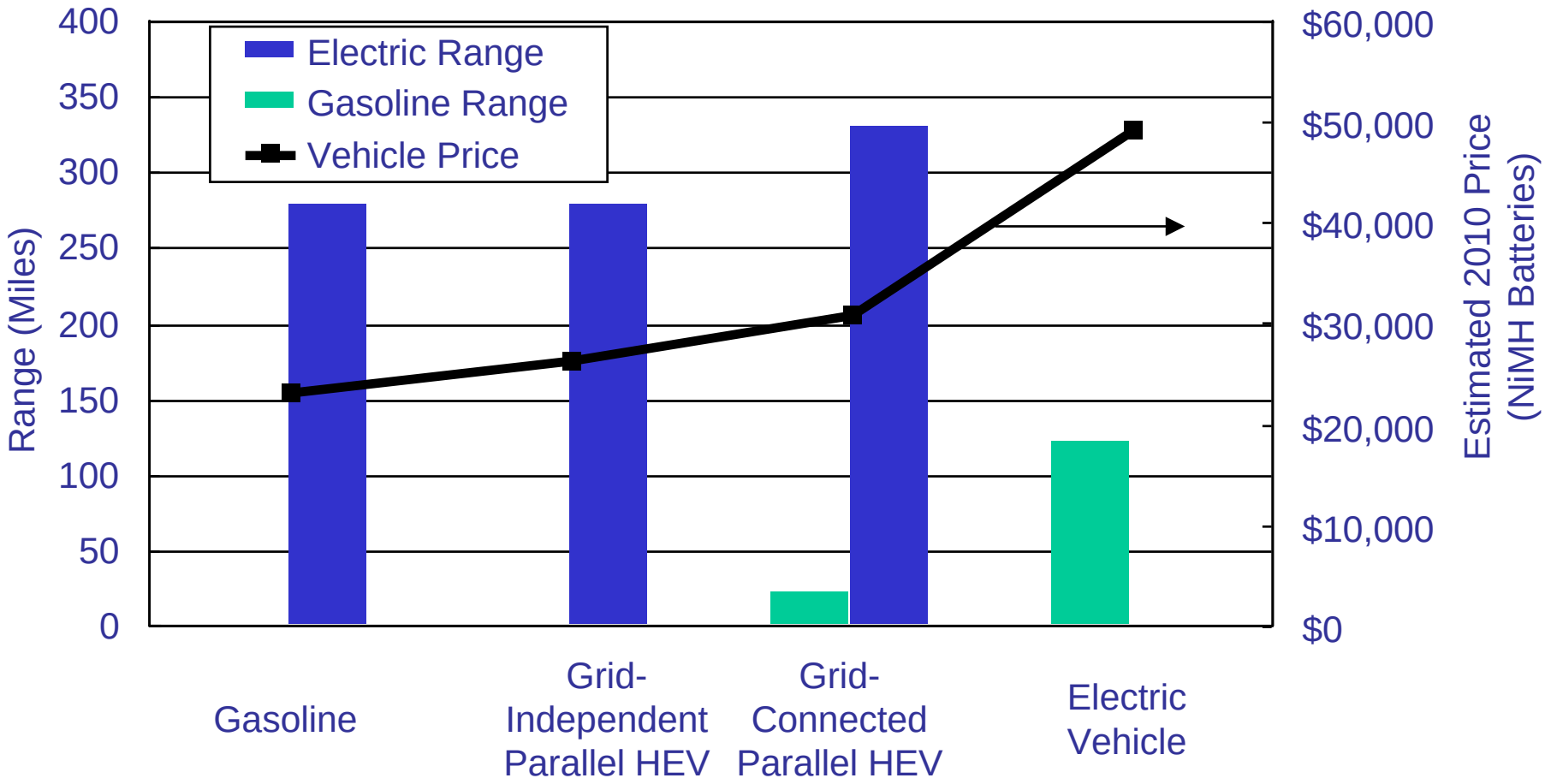
Fuel cost is important only for small and compact cars & sport utility vehicles. Purchasers of small and compact cars are sensitive to purchase price.

Variable	Vehicle Type+	Coefficient	Standard Error	Z-Value
Purchase price	Neighborhood EV, small and compact car, minivan	-9.21E-05	1.70E-05	-5.41
	Midsize and large car, compact pickup, standard van, sport utlity, standard sport utility	-3.27E-05	2.34E-02	0.02
Minimum fuel cost* (¢/mile)	Neighborhood EV, small and compact car, minivan	5.59E-04	2.34E-02	0.02
	Midsize and large car, compact pickup, standard van, sport utlity, standard sport utility	-1.42E-01	2.55E-02	-5.50

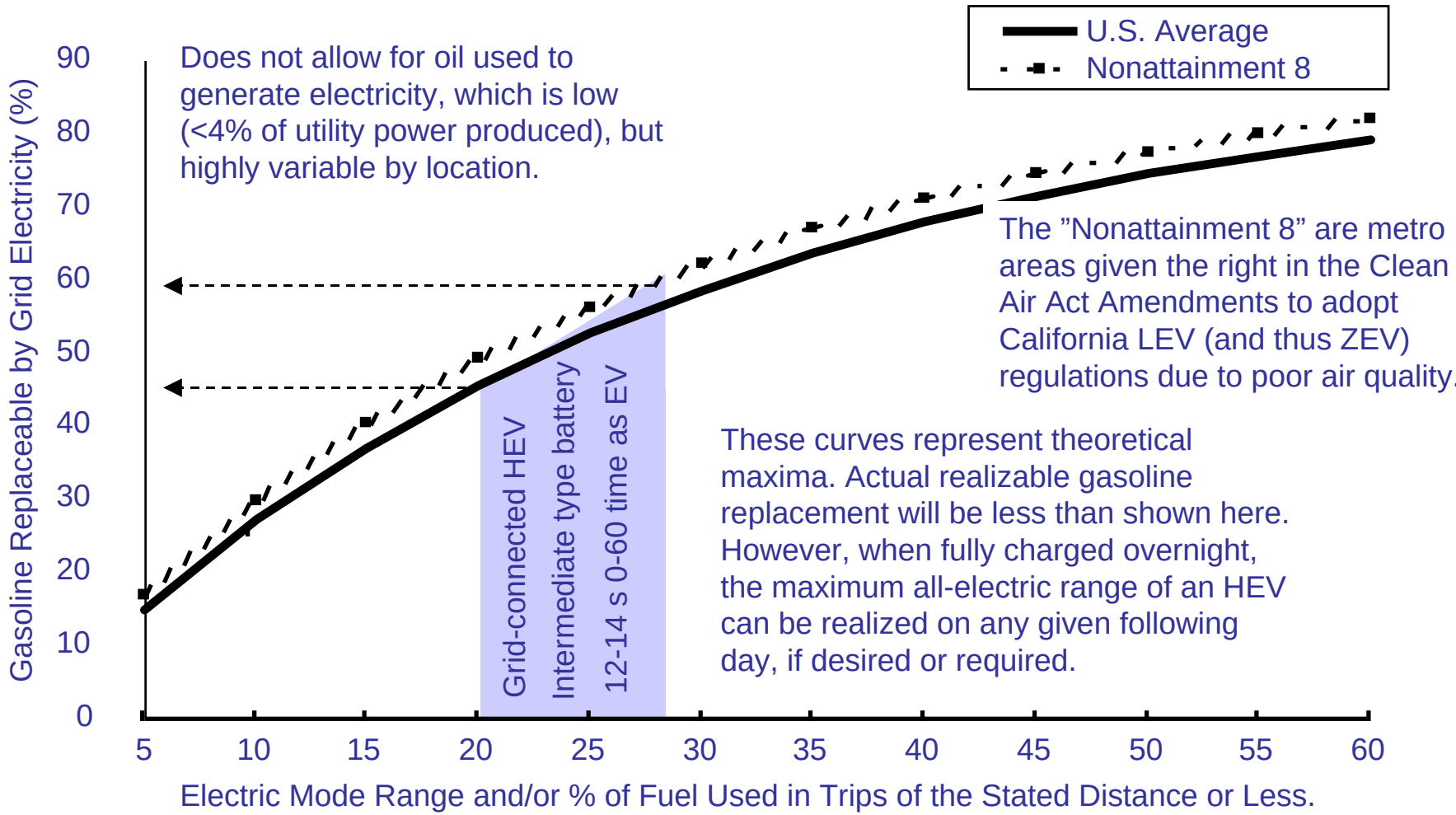
+ Groupings based on numerous experiments on equality vs. difference of model-specific coefficients

* When descriptions included several fuel prices (e.g., grid HEVs could have three: gasoline, on-peak and off-peak electricity), it was assumed that respondent evaluation on the basis of a minimum of the choices was a good as separate estimates for primary and alternative fuel.

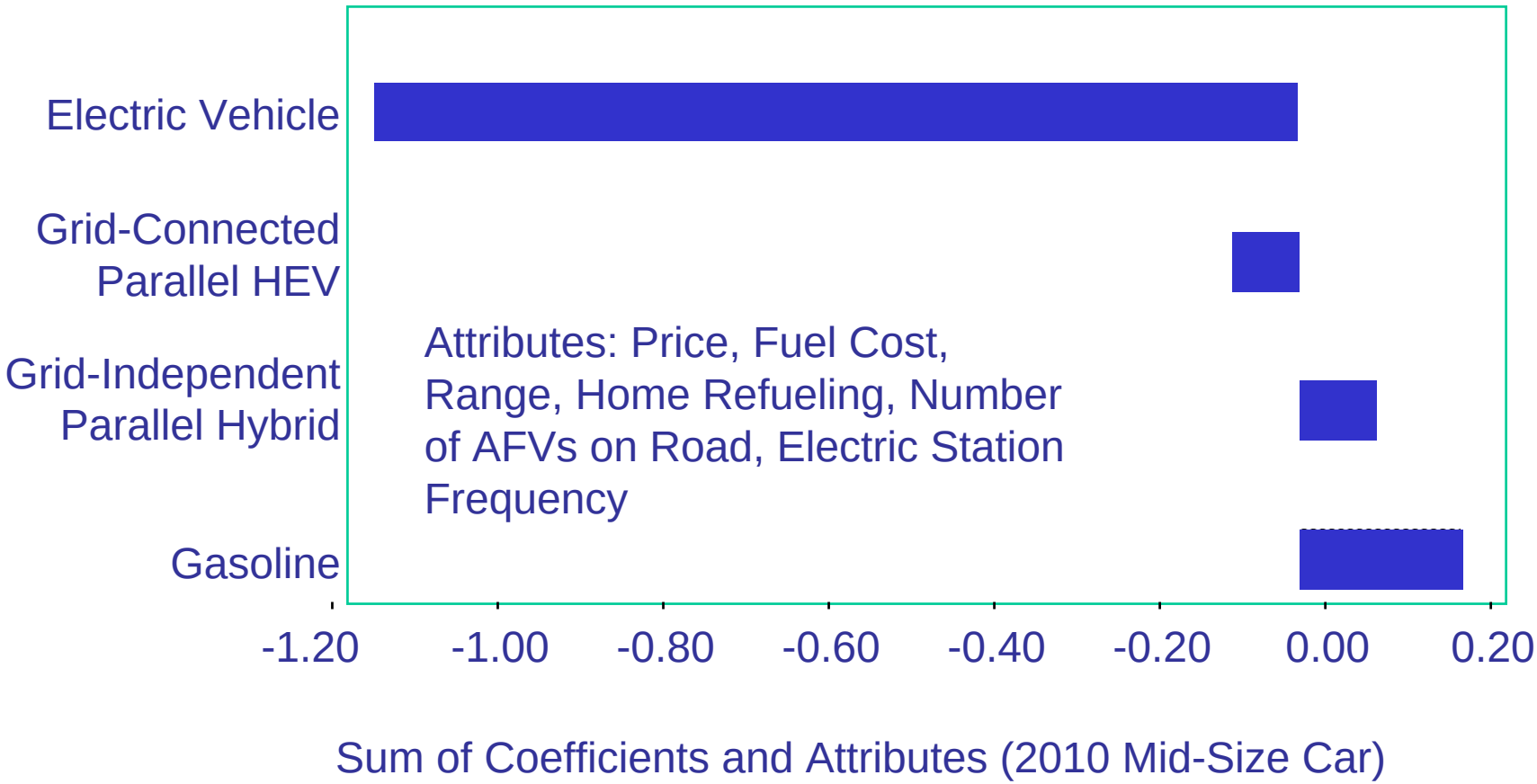
Electric range is expensive. Cost of range is the missing link in EV marketability.



Maximizing grid charging, an ultralight HEV with purpose-built battery & ZEV performance could cut oil use significantly beyond fuel economy benefits that the HEV would also have. Many such vehicles could operate in ZEV mode for entire "ozone action days." An EV could cut oil use and emissions even more.



Sum of products of coefficients and attributes (satisfaction index) indicates that EVs will capture only a small share (because of high price). Grid HEVs seems likely to be more marketable.



Observations

- In view of the high costs of range in all EVs, it seems doubtful that all EVs can broadly compete with gasoline vehicles.
- Though the value of gasoline range for a grid-connected HEV with home refueling is not large compared with that of a gasoline vehicle, the reduction in cost of all-electric range and thus in total vehicle cost makes a grid-connected HEV a far more likely way to obtain the benefits of all-electric operation in a broadly marketable package.

Speculation on Implications When Using Statistical and Cost Models in a Vehicle Choice Model

- EVs require higher fuel prices and/or subsidies to broadly compete with conventional gasoline vehicles.
- Grid-independent HEVs are most likely to succeed against gasoline vehicles if gasoline costs rise.
- If all-electric operation capability is desires for social cost reasons, grid-connectable HEVs are likely to be the cheapest way to obtain the greatest grid electric use.

APPENDIX:
SUPPLEMENTAL OBSERVATIONS

(prepared after the conference)

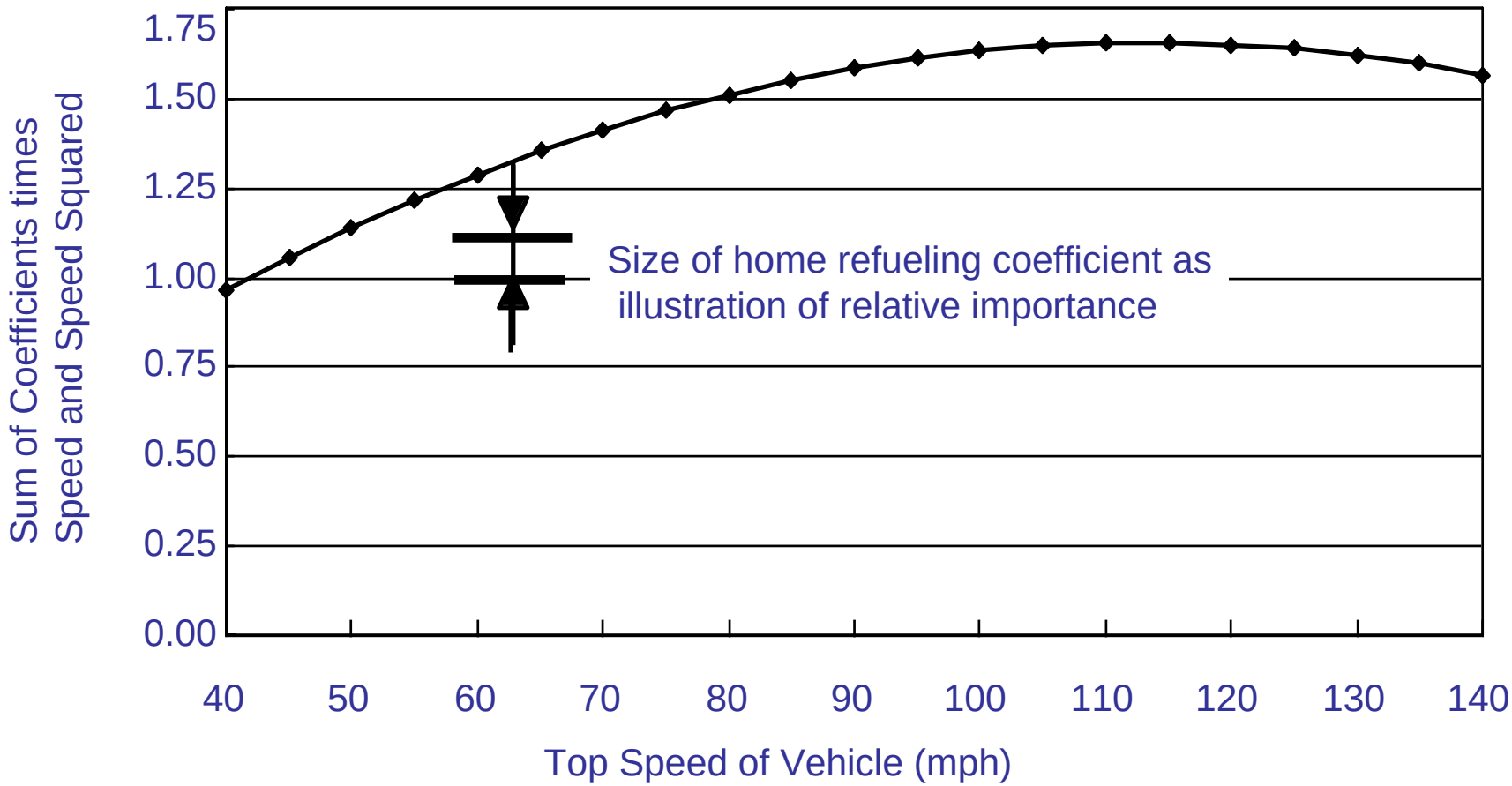
Not all factors potentially detrimental to EVs are included.

The survey model includes battery cost, acceleration, top speed, & luggage space.
When separated, small and compact car coefficients are larger and more clearly significant.

Variable	Vehicle Model	Coefficient	Standard Error	Z-Value
Annualized battery cost plus maintenance cost	All	-5.28E-04	1.76E-04	3.01
Acceleration (0-30 mph)	All except those below	-1.38E-02	2.75E-02	-0.50
	Small/compact cars, minivans	-1.19E-01	4.33E-02	-2.75
Top speed	All	2.91E-02	1.51E-02	1.81
Top speed squared	All	-1.28E-04	7.88E-04	3.01
Luggage space	Small/compact cars, minivans	1.66E-02	4.85E-03	3.42
	Compact/standard pickups, standard van*	-1.96E-02	5.30E-03	-3.69
	Midsize/large cars, minivans	2.85E-03	4.64E-03	0.62

* “Work truck” customers who are speculated to regard luggage space as encroaching on cargo space. No descriptions of cargo space or carrying capacity were included in the survey.

The respondents' value of top speed peaked at 114 mph.



Once there are 400,000 flex-fuel vehicles in a region, they should be as acceptable as gasoline vehicles at likely ranges offered.